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Mechanism Of VOC Release From High-Temperature Southern Pine Lumber Drying -

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Abstract

Hydrocarbon (Method 25A) emissions from drying southern pine lumber have been measured in full-scale experiments. The mechanism proposed comprises three components: release of turpentine dissolved in the surface layer of water on the wood, water-mediated transport of turpentine from the interior of the wood to the surface, and evaporation of turpentine during the falling rate period. The result allows the total Method 25A release to be estimated without knowledge of the airflow through the kiln. Full-scale Method 25A emissions from lumber can be predicted from laboratory work on sawdust, indicating that the mechanism is independent of the type of furnish.

Keywords: VOCs, kiln drying, turpentine, pinene, Method 25A emissions

Introduction

The measurement and control of VOC emissions are of current interest since regulatory compliance is expensive. To date, the source of VOCs and the factors that govern their release have been addressed empirically, *e.g.* through study of the relationship between VOCs and operational parameters such as temperature and wood geometry (Shmulsky 2000 a,b,c; Shmulsky and Ingram 2000). Also, seasonal factors significantly affect the amounts of monoterpenes (the predominant VOC component) present in living southern pine trees (Conners et al. 2001).

Banerjee (2001) has shown that the concentration vs. time profile for VOC release from softwood flakes or particle has three regions. There is an initial burst very early in the drying process. The VOCs then emerge in a near-constant amount until the wood is almost dry, at which point the emissions increase. The location of the first peak is independent of dryer temperature, suggesting that it originates from surface material while the wood warms up. Pinene and water are then released in a near-constant ratio, which is ascribed to water mobilizing pinene from the interior of the wood matrix to the wet line. The surfactants present in wood are believed to solubilize pinene into water. Finally, pinene is lost through evaporation when the wood is almost dry. In this paper we demonstrate that this mechanism of VOC release applies to the commercial drying of lumber, and that emissions from lumber kilns can be estimated without knowledge of the airflow through the kiln.

Experimental

Southern pine lumber was dried in a relatively new commercial southern pine dry kiln in the Southeastern US. The wood was dried to a target MC of 14–14.5% through indirect heating with steam coils; the loads were mixed charges of 2 x 10's and 2 x 12's, with a volume of about 105,000 b.f. The dry bulb temperature was ramped up to 100°C in three hours and then gradually increased, reaching 115°C by the end of the run (about 17.5 hours). The vents were kept closed

for the first four hours (*i.e.*, the warm-up period plus one additional hour), and then the exhaust vents were opened fully for the duration of the run. The intake vents were kept closed throughout; hence the data collected generally represent actual changes in the kiln atmosphere resulting from lumber drying with minimal influence of external air infiltration.

Hydrocarbons emissions were measured during July and November 2000 with a JUM Model VE7 analyzer using Method 25A (Anonymous 1995) and are reported on an as-propane basis. The emissions were measured after diluting the kiln air sample with an equal amount of hydrocarbon-free air to minimize instrument problems caused by the high sample humidity. The samaple to be analyzed was prepared by balancing (and then combining) the flows from the two separate gas input streams: (1) from the kiln atmosphere and (2) from the air tank. Air samples from within the kiln were also collected hourly in chilled methanol impingers, and the trapped α-pinene was determined by gas chromatography. The condensed water was weighed to calculate the water:analyte ratio.

A trailer was sited adjacent to the kiln to house instrumentation, and sampling probes were inserted at breast height through two gasketed holes in the kiln wall to determine whether the air flow and/or sampling location might affect the measurements. One was placed close to the kiln entrance; the second was positioned at the middle of the kiln. Each probe was a 70-cm long piece of 0.6 cm copper tubing (preheated to over 200°C) tipped with a fine mesh filter. Method 25A measurements were made continually at both locations; kiln air was sampled through heated lines to avoid condensation problems. The values from the two probes were almost identical, confirming that the kiln volume was well-mixed.

Results and Discussion

Emissions were measured during commercial dry kiln runs in July and November 2000, and representative profiles are illustrated in Figure 1. All runs were replicated, and the replicates within each sampling event agree very well. The November emissions are somewhat higher than those in July, possibly because of seasonal factors (Conners *et al.* 2001). Profiles of α-pinene and water are illustrated in Figure 2; there is a remarkable mirror-image relationship. The high initial α-pinene signal in Figure 1 is believed to reflect loss of surficial material, as discussed earlier for particle and flakes. α-Pinene is then lost along with water at an approximately constant ratio from 5–13 hours. Finally, local overdrying occurs during the falling rate period and the VOCs rise as the water emissions taper off. Note that the pinene:water ratio (in Figure 2) after the vents are opened after four hours is approximately 0.1%. This is the same value obtained earlier for laboratory measurements on particle (Banerjee 2001), and suggests that the same mechanism applies to both lumber and particles.

If the pinene released is 0.1% -of the water lost from drying lumber, then 2.1 lbs/Mbf of α-pinene would be released when lumber was dried from a moisture content of 100 to 15%,. The final uptick in Figure 1 that reflects overdrying must now be added, and this increases emissions by about 35%. α-Pinene represents about two-thirds of the total turpentine emissions from southern pine, and therefore a value of 4.4 lbs/Mbf is calculated for Method 25A emissions after the vents were opened.

Emissions for the first four hours when the vents were closed can be estimated through the following analysis. The emissions will principally occur through leaks as the air within the kiln expands from an ambient temperature to 100°C. The VOC concentration in the commercial kiln averages about 2,000 ppm during the first four hours, and the kiln volume less the volume of the wood is approximately 52,000 cu ft. Heating this volume from ambient temperature (say 30°C) to 100°C expands it by 23%. The amount of VOC contained in this volume is 0.5 lbs/MBf. If this is added to the emissions estimated for the remainder of the kiln cycle, then an overall value of 4.9 lbs/MbF or 3.9 lbs/dry ton results, which compares well with results from a recent multi-facility study on lumber drying (Otwell, 2001). Importantly, the calculation does not consider airflow at all. Airflow is notoriously difficult to measure in the field since the vents open and close periodically and the volume of air released varies continuously.

Except for the initial spike, the emissions are normalized with respect to the water lost. Hence, the contribution of leaks is relatively unimportant, since the calculation does not consider *how* the emissions leave the kiln, only that it does so. Key features of the approach are that the VOCs and the water in the headspace are uniformly distributed, and that pinene is released as a constant fraction of water for most of the drying cycle. There are two major sources of variability. The 0.6 lbs/Mbf value for the initial closed-vent period is load-specific. It, and the 35% adjustment for the final uptick will depend on factors such the kiln layout, drying conditions and final moisture content. It is important to remember that the basis of the calculation, the α-pinene:water ratio of 0.1% was derived from laboratory work with sawdust and can also be applied to emissions from drying OSB furnish (Banerjee 2001). Hence, the mechanism of VOC emissions from wood seems to be similar across furnish types.

Conclusions

A mechanism for VOC emissions developed from laboratory work on particle and flake was successfully applied to full-scale emissions from drying softwood lumber. There is an initial VOC surge as the wood heats up and surficial terpenes are released. The VOCs then leave as a constant fraction of the water lost until the falling rate period is reached, Portions of the wood then over dry and release additional VOC. Emissions estimated from these mechanistic considerations agree well with full-scale field data. This allows us to estimate VOC releases without measuring airflow, which is very difficult to measure in the field.

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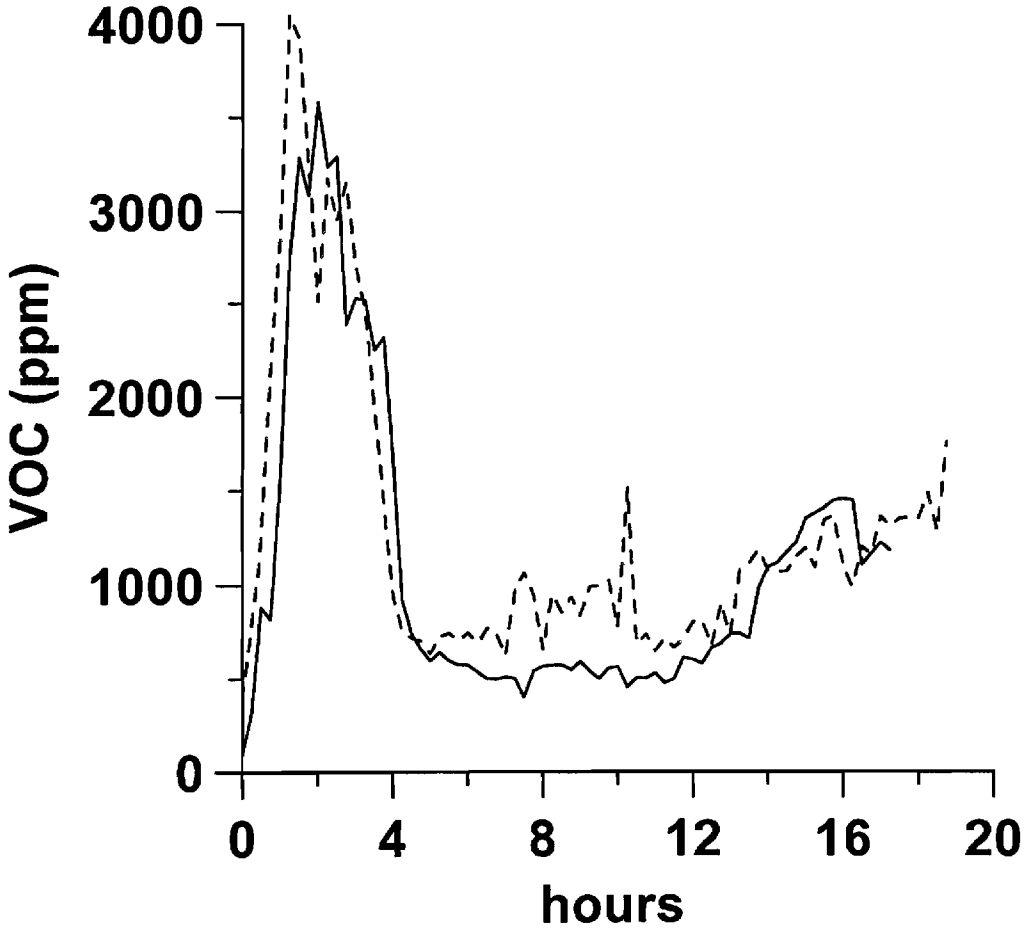

Figure 1. Method 25A profiles collected in July 2000 (bold) and November 2000 (dashed).

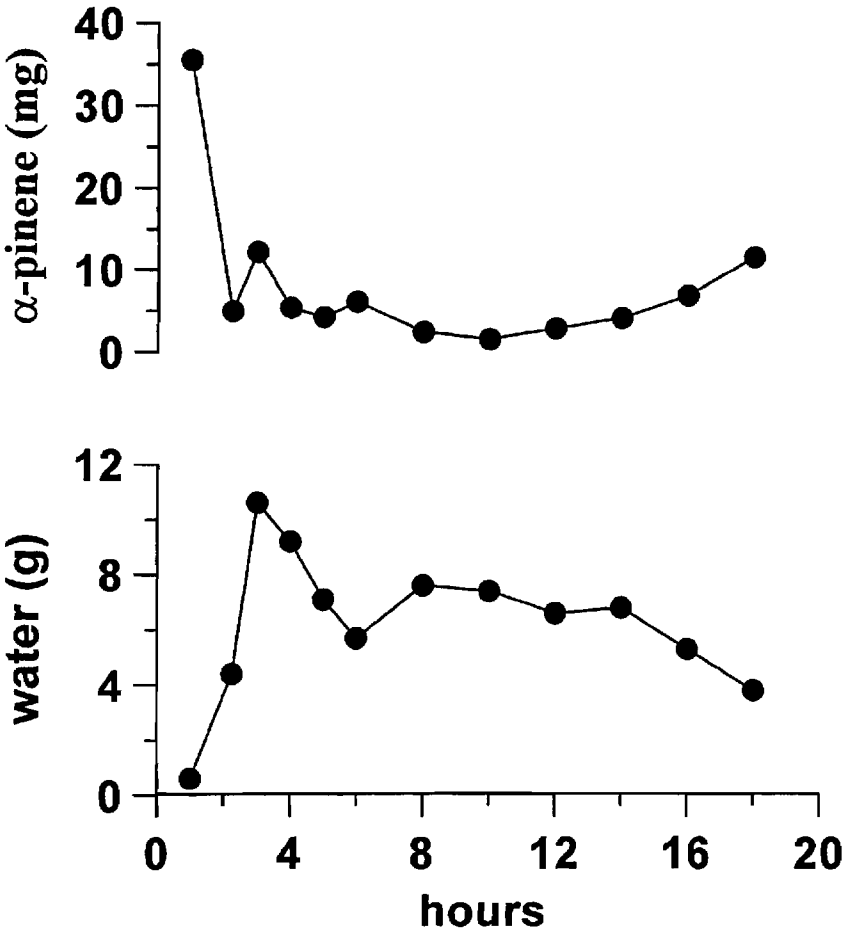

Figure 2. Pinene and water profiles collected in July 2000.